NAME (as it appears on your UF ID): ______________________________

(Please **PRINT**)

UF Student ID#: ______________

------------------------- CEN 6070 Software Testing & Verification -------------------------

Exam 2 – Summer 2015

You have 90 minutes to work on this exam. It is a "closed-book/closed-notes" test. Pay attention to point values, since you may not have time to complete all 12 problems. **You should assume that all variables represent INTEGERS, unless otherwise indicated.**

PRINT your name above NOW and sign the pledge at the bottom of the last page, if appropriate, when you are finished.

You will be given "scratch paper," but PLEASE PRINT ANSWERS IN THE SPACE PROVIDED ON THE EXAM **(EXCLUDING MARGINS)** ONLY – PREFERABLY USING A BALLPOINT PEN TO INCREASE LEGIBILITY. Good luck!

1. (16 pts.) Consider the assertion of ***weak*** correctness: {t=5 ∧ z<0} S {y=z+1 ∧ t=z}. Which of the following observations/facts **would** allow one to deduce that the assertion is false, and which **would not**? Circle either "would" or "would not" as appropriate, considering the observations individually. To compensate for random guessing, your score in points will be 2 times the number of [correct minus incorrect] answers, or 0 – whichever is greater. Therefore, if you are not more than 50% sure of your answer, consider skipping the problem.

   a. sp(S, z=-5) = t≠z — would / would not

   b. Whenever the product of t and z is equal to -5 prior to the execution of S, S terminates with t≠z. — would / would not

   c. wlp(S, y=z) = z>-5 — would / would not

   d. When the initial value of t is 5 and the initial value of z is -5, S terminates with t=17. — would / would not

   e. wp(S, y=z) = z>-5 — would / would not

   f. When the initial value of t is 5 and the initial value of z is -17, S does not terminate. — would / would not

   g. wp(S, t=z) = |t|>2 — would / would not

   h. Whenever the initial value of z is -7, S terminates with y sometimes being less than z. — would / would not

2. (18 pts.) Circle either "true" or "false" for each of the following assertions. To compensate for random guessing, your score in points will be 2 times the number of [correct minus incorrect] answers, or 0 – whichever is greater. Therefore, if you are not more than 50% sure of your answer, consider skipping the problem.

a. Suppose sp(S,k) = t. Then wlp(S, t) $\Rightarrow$ k. — true — false

b. [{x>0} S {x>0}] $\Rightarrow$ [{x=5} S {x=5}] — true — false

c. Suppose k = wp(while b do S, Q). Then k is a Q-adequate loop invariant for {P} while b do S {Q} for any P that guarantees termination of S. — true — false

d. {x>5} while x<>5 do x := x-3 {x≥5} — true — false

e. {P} while b do S {Q} $\Leftrightarrow$ — true — false

```
{P}
   if b then
      S
   end_if
   repeat S until NOT b
{Q}
```

f. [sp(S, x≥5) = (y=17)] $\Rightarrow$ [{x=5 ∧ z=0} S {y<25}] — true — false

g. The Method of Well Founded Sets, as presented in class, can be used to prove that the program below will terminate for some initial values of x,y. — true — false

```
while (y>0) do
   y := y+x
   if (x≥0) then
        x := x-1
   end_if
end_while
```

h. Formally speaking, Z=XJ is a **loop invariant** for the assertion: — true — false

```
{Z=0 ∧ J=0}
     while J<=Y do
         Z := Z+X;
         J := J+1
     end_while
{Z=XY}
```

i. Z=XJ ∧ J≥0 is a **Q-adequate loop invariant** for the assertion given in part (h) above. — true — false

3. a. (2 pts.) Complete the ROI for proving the weak correctness of program S with respect to pre-condition P and post-condition Q using the weakest liberal pre-condition (**wlp**) predicate transform:

$$\frac{\rule{6cm}{0pt}}{\{P\}\ K\ \{Q\}}$$

b. (15 pts.) Find the weakest liberal pre-condition (wlp) of the program:

K: while t<>0 do t := t-1; z := z+y end_while

with respect to the post-condition {z=yx}. (Give the values of H_0, H_1, H_2, and H_k, where the **wp**(K,Q) is given by the infinite expression: $H_0 \vee H_1 \vee H_2 \vee \ldots \vee H_k \vee \ldots$ and then express the **wlp**(K,Q) in closed form.) ASSUME that the weakest pre-condition ensuring the termination of K (only) is $t \geq 0$.

H_0:

H_1:

H_2:

H_k:

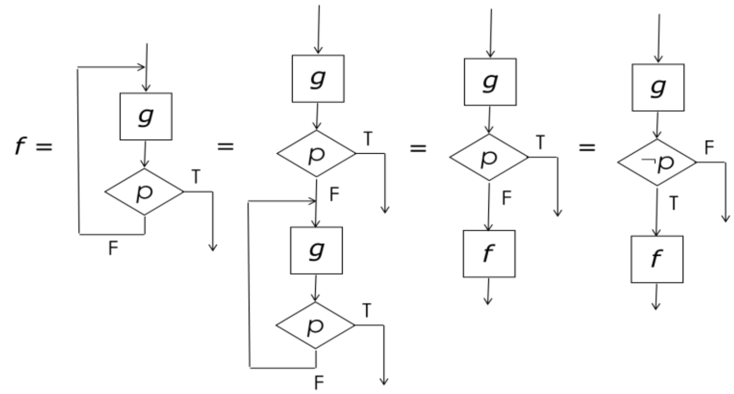
Closed form expression of **wlp**: ______________________________________

c. (6 pts.) Use the ROI from part (a) and the closed form expression of the wlp from part (b) to prove the assertion:

{|t|=3 ∧ x=5 ∧ z=4 ∧ y=2} while t<>0 do t := t-1; z := z+y {z=10}

Note that, by observation, the values of both x and y are invariant with respect to program K.

4. (3 pts.) The diagram below was used in class to illustrate an important concept/result related to functional verification.



Which one of the following concepts/results was derived in connection with the control flow relationships illustrated? (Circle ONE only.)

a. the Rule of Inference for proving {P} *repeat g until p* {Q}

b. the functional relationship between repeat_until and while_do constructs

c. the weakest possible *f*-adequate loop invariant for [*repeat g until p*]

d. the Axiom of Replacement

e. the weakest pre-condition of *repeat g until p* with respect to post-condition Q

f. the complete correctness conditions for *f* = [*repeat g until p*]

g. (none of the above)

5. (8 pts.) Given *P1, P2, f1,* and *f2:*

P1 = while x>2 do x := x-1; z := z∗x end_while

P2 = while x<>1 do x := x-1; z := z∗x end_while

f1 = (x=2 -> x, z := 1, z | x≤1 -> x, z := x-1, zx-z)

f2 = (x>1 -> x, z := 1, z(x-1)!)

Determine the correctness relationships among the given programs and functions. In the table below, indicate "C" for Complete program correctness, "S" for Sufficient program correctness only, and "N" for Neither. To compensate for random guessing, you will receive +2 pts. for each correct answer given and -1 pt. for each incorrect answer given, with a minimum possible score of 0 pts.

	P1	*P2*
f1		
f2		

6. (20 pts.) Circle either "valid" or "invalid" for each of the following *hypothesized* Rules of Inference. To compensate for random guessing, your score in points will be 2 times the number of [correct minus incorrect] answers, or 0 – whichever is greater. Therefore, if you are not more than 50% sure of your answer, consider skipping the problem.

a. $$\frac{\{\text{true}\}\ \text{if } b \text{ then } S\ \{Q\}\ \text{strongly}}{\{P\}\ \text{while } b \text{ do } S\ \{Q\}\ \text{strongly}}\ ?$$ valid invalid

b. $$\frac{\{\text{true}\}\ \text{if } b \text{ then } S\ \{b \vee Q\}}{\{P\}\ \text{while } b \text{ do } S\ \{Q\}}\ ?$$ valid invalid

c. $$\frac{\{\text{true}\}\ S\ \{K\},\ \{K\}\ \text{while } \neg b \text{ do } S\ \{Q\}}{\{P\}\ \text{repeat } S \text{ until } b\ \{Q\}}\ ?$$ valid invalid

d. $$\frac{sp(S, P) \Rightarrow \text{true}}{\{P\}\ S\ \{Q\}}\ ?$$ valid invalid

e. $$\frac{P \Leftrightarrow I,\ \{I\}\ S\ \{I\},\ P \Rightarrow Q}{\{P\}\ \text{repeat } S \text{ until } b\ \{Q\}}\ ?$$ valid invalid

f. $$\frac{(\neg b) \Leftrightarrow Q}{\{P\}\ \text{while } b \text{ do } S\ \{Q\}\ \text{strongly}}\ ?$$ valid invalid

g. $$\frac{\{\text{true}\}\ S\ \{I\},\ (I \wedge b) \Rightarrow Q}{\{P\}\ \text{repeat } S \text{ until } b\ \{Q\}}\ ?$$ valid invalid

h. $$\frac{Q \Leftrightarrow sp(S, \text{true})}{\{P\}\ S\ \{Q\}}\ ?$$ valid invalid

i. $$\frac{(wlp(S, Q) \wedge K) \Rightarrow P}{\{P\}\ S\ \{Q\}}\ ?$$ valid invalid

j. $$\frac{\{P \wedge b\}\ S\ \{I\},\ ((I \vee P) \wedge \neg b) \Rightarrow Q}{\{P\}\ \text{while } b \text{ do } S\ \{Q\}}\ ?$$ valid invalid

7. (10 pts.) Prove the assertion of weak correctness below using the while loop Rule of Inference with the invariant: $t=2^k$. SHOW AND JUSTIFY ALL STEPS AND CASES AS ILLUSTRATED IN CLASS.

$\{n \geq -17\}$

```
t := 1
k := 0
while k<>n do
    t := 2*t
    k := k+1
end_while
```

$\{t=2^n\}$

8. (19 pts.) For program *H* and intended program function *f* given below, Prove *f* = [*H*] by showing that the while_do complete correctness conditions hold. You may <u>assume</u> (i.e., you need NOT prove) that the function of the loop body, *g*, is (t,k := 2t,k+1). STATE AND **PROVE** ALL OTHER CONDITIONS, STEPS, AND CASES AS ILLUSTRATED IN CLASS.

H:
```
while k<>n do
   t := 2*t
   k := k+1
end_while
```

$f = (k \le n \rightarrow t,k := t2^{n-k},n)$

(Continue your proof on the next page if necessary.)

8. (cont'd)

9. a. (10 pts.) Assume that for "input" $X_0 = (y_0, z_0)$, a while loop computing function t terminates after n iterations with "output" $X_n = (y_n, z_n) = (0, z_0+5|y_0|)$. Furthermore, assume $X_1, X_2, \ldots, X_k, \ldots, X_{n-1}$ are the intermediate states generated by the loop.

   i. What is $t(X_{k=3})$?

   ii. What is $t(X_n)$?

   iii. Give the weakest t-adequate invariant, $q(X)$, for *any* while loop computing this function.

b. (4 pts.) Suppose it was determined that $t(X_k) = (0, -1)$. Could one then deduce a unique X_0 from this fact? **If so**, what would the unique values of y_0 and z_0 be? **If not**, what *could* be deduced about y_0 and z_0?

c. (4 pts.) Is there a program of the form *while b do S* that could compute t and produce intermediate state (-2,3) for some input? (Circle ONE only.)

   i. Yes, every program of the form *while b do S* that computes t would produce intermediate state (-2,3) for some input.

   ii. No, since for any input, the intermediate state (-2,3) is inconsistent with the invariant $q(X)$ for t.

   iii. Yes, there could be a program of the form *while b do S* that computes t and produces intermediate state (-2,3) for some input *provided* that the program terminates with y=0 and z=13.

   iv. Yes, every program of the form *while b do S* that computes t and terminates with y=0 and z=13 would produce intermediate state (-2,3) for some input.

   v. (None of the above – this cannot be determined based on the info provided)

d. (4 pts.) Suppose "input" $X_0 = (y_0, z_0) = (4,-1)$. Is there a program of the form *while b do S* that computes $t(4,-1)$ that could also generate intermediate state (1,14)? Briefly justify your answer.

10. (10 pts.) The following statements relate to King, et al., "Is Proof More Cost Effective than Testing?" Indicate whether each is true or false. To compensate for random guessing, your score in points will be 2 times the number of [correct minus incorrect] answers, or 0 – whichever is greater. Therefore, if you are not more than 50% sure of your answer, consider skipping the problem.

a. Substantial amounts of unit testing were completed before the bulk of code proof started.	true	false
b. The application described in the paper, "SPARK", is a Z-specified compiler implemented in a subset of Ada that is used for procuring safety critical software for defense systems.	true	false
c. Code proofs made use of predicate transforms for non-looping programs, while invariants plus separate arguments for termination were used for loops.	true	false
d. A "lesson learned" by the authors was that at the "top" level of the system, proof annotations were often too large to be manageable, while at the "bottom" there was a need to interface with software (such as device drivers) for which there was *no* formal specification.	true	false
e. When the customers reviewed a sample of the Z proofs (selected by them), only typographical errors were found.	true	false

11. (10 pts.) The following statements relate to Linger, "Cleanroom Software Engineering for Zero-Defect Software." Indicate whether each is true or false. To compensate for random guessing, your score in points will be 2 times the number of [correct minus incorrect] answers, or 0 – whichever is greater. Therefore, if you are not more than 50% sure of your answer, consider skipping the problem.

a. Linger notes that while the Cleanroom process is readily applied to new systems development, re-engineering and extension of existing systems require the use of other, more traditional processes.	true	false
b. The Cleanroom process is based on the philosophy that *developers need to be comfortable with testing less. "The key aspect is to balance...the feature set and (their) quality... If it is too high, then you won't be competitive in the market place and your code won't be exercised."*	true	false
c. The system-level test team is responsible for "measuring quality" using error seeding and mutation analysis.	true	false
d. A significant advantage of testing based on the expected frequency of user executions (from an operational profile) over coverage testing is that flaws in high-consequence functions will be found first.	true	false
e. Cleanroom management planning and control is based on developing and certifying a pipeline of software increments that accumulate to the final product.	true	false

12. (12 pts.) Use the Axiom of Replacement and function composition to *deduce* the function of the following program:

```
y := x+1
if y>0 then
   x := x-1
else
   y := 1-y
end_if_else
x := y-1
```

Express the function as: ($p_1 \rightarrow$ x,y := ?,? | $p_2 \rightarrow$ x,y := ?,?) where p_1 and p_2 are Boolean predicates, the union of which specifies the function domain.

On my honor, I have neither given nor received unauthorized aid on this exam and I pledge not to divulge information regarding its contents to those who have not yet taken it.

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SIGNATURE